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SEVGİ POYRAZ ENGİN

CEVRİYE MERT

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The effects of harvesting time on the physicochemical components of aronia berry

Sevgi POYRAZ ENGİN[1,*], **Cevriye MERT**[2]
[1]Atatürk Horticultural Central Research Institute, Yalova, Turkey
[2]Department of Horticulture, Faculty of Agriculture, Uludağ University, Bursa, Turkey

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Abstract: The aim of this work was to compare 'Nero' and 'Viking' aronia cultivars and to determine the optimum harvest dates of each cultivar for various utilizations. For this purpose, we characterized the changes in both aronia cultivars' physicochemical components over their harvest period and identified the correlations between them. Mean berry weight, dry matter, soluble solid content, antioxidant activity, and anthocyanin content of berries of both cultivars increased until the second and third weeks of September. They then began decreasing gradually, whereas total phenol content and condensed tannins kept increasing until 27 October. It was observed that berries of 'Nero' ripened 15 days earlier than those of 'Viking'. As a result, anthocyanin content of 'Nero' peaked earlier (25 August) than that of 'Viking'. The highest correlation ($r = 0.75$, $P < 0.01$) was found between anthocyanin and firmness; antioxidant activity was slightly correlated with total phenol content ($r = 0.57$, $P < 0.01$) and total anthocyanin ($r = 0.49$, $P < 0.05$). In terms of yield, the optimum harvest time for both cultivars was found to be the second week of September. Taking also into account the anthocyanin content, antioxidant capacity, and total phenol, the optimum harvest time was determined to be during the second and third weeks of September. On the other hand, the optimum harvest time for dry consumption was found to be during the first and second weeks of October.

Key words: Anthocyanin content, aronia berry, harvest time, physicochemical components

1. Introduction

Fruit species are a very diverse group, including numerous cultivars, accessions, genotypes, etc. (Halasz et al., 2010; Alibabic et al., 2018). Underutilized or minor horticultural fruits have been gradually growing in popularity as potential economic fruit crops. Many of them are a key source of qualitative nutritive traits and high medicinal properties (Serce et al., 2010; Eyduran et al., 2015; Guney et al., 2019).

Aronia, also called black chokeberry (*Aronia melanocarpa*), originates from North America, including Canada (Andrzejewska et al., 2015). It was imported to Europe in the beginning of the 20th century due to its potential health benefits (Esatbeyoğlu and Winterhalter, 2010). Dark-colored fruits, particularly berries, are recognized as being healthy (Ercisli et al., 2010). Aronia is high in anthocyanin content and antioxidant capacity compared to other berries. Aronia fruits have rich content in terms of vitamins, minerals, and folic acid. Aronia berries are consumed fresh, dry, or juiced, or processed as jams, extracts, or food colorants. They are rich in anthocyanin and other phenols. These polyphenols contribute to the high antioxidant activity of aronia extracts. It is known that the degree of berry maturity affects the quantity and quality of phenolic compounds, which largely determine the antioxidative activity of berries (Andrzejewska et al., 2015). Fruit quality of aronia berry depends on a series of factors such as cultivar, fertilization, maturation of berries, harvest date, and locations (Jeppsson and Johansson, 2000; Kulling and Rawel, 2008).

Aronia is unique among berries because its berries are ripe and apparently harvestable for nearly 2 months, which allows for a considerable variation in the composition of berries (Kulling and Rawel, 2008; Poyraz Engin et al., 2018). Thus, data for the extent that aronia polyphenols and other components vary during the harvest period are expected to improve horticultural practices and aronia berry composition (Bolling et al., 2015).

Only a few data can be used in the determination of optimum harvest times for different uses. In Poland, aronia berries can be harvested from mid-August to October (Kawecki and Tomaszewska, 2006). In Sweden, the optimal harvest time has been determined as 8 September, when anthocyanin content also reaches its maximum (Jeppsson and Johansson, 2000). In Poland, the traditionally recommended harvest time falls at the end of August. Such an early time facilitates the organization of harvesting and processing, but raw material of a better

* Correspondence: sevgi.engin@tarimorman.gov.tr

quality can probably be obtained from a later harvest, because mature fruits remain on shrubs until first frosts (Andrzejewska et al., 2015).

Recently, commercial aronia plantations have been established in Turkey, but growers do not have enough information regarding the effects of different harvesting times on the contents of berries. Thus, the current study may provide growers with crucial information about the pomological, biochemical, and phytochemical contents of the berries during different harvest times.

It is widely known that physicochemical components of berries change through the ripening process. However, the correlations between them are not clear yet. Aronia cultivation and consumption of its berries fresh, dry, juiced, as colorant, and as a source of nutraceuticals for functional food products are increasing in Turkey (Poyraz Engin and Mert, 2018). Thus, the primary objectives of the present study are to characterize the changes in both aronia cultivars' physicochemical components during their harvest period and to identify the correlations between them. Our goal was to compare 'Nero' and 'Viking' aronia cultivars and to determine the optimum harvest dates of each cultivar for various utilizations.

2. Materials and methods

2.1. Plant materials

'Nero' and 'Viking' cultivars of aronia (*Aronia melanocarpa* (Michx.) Elliot.) were used in this study. Aronia plants were grown in the test area of Atatürk Horticultural Central Research Institute in Yalova (located in the northwest of Turkey). The plantation was 5 years old. The test area was set up as 3 m × 2 m plots, and fertilized at regular intervals with mineral nutrients together with drip irrigation water during the vegetation period. Fertilizer with nitrogen in 2 doses of 2 kg N/da each was used. Phosphorus and potassium fertilizers were not applied because they were already present in the soil. The soil structure was loamy. Since aronia plants are naturally resistant to pathogens, pesticide was not applied.

2.2. Harvest method

To determine harvest period and optimum harvest times for various uses, the physicochemical components of berries harvested on 6 different dates in 2017 were measured. Berry samples of both cultivars were collected on 15 August (date 1), 25 August (date 2), 11 September (date 3), 26 September (date 4), 12 October (date 5), and 27 October (date 6). At the beginning of the study, 4 blocks from both cultivars and 4 shrubs from each block, 32 shrubs in total, were randomly selected. On each harvest date, berries on a plant having plentiful berries randomly selected from these shrubs (11–17 plants in each shrub) were collected from the bottom to the top. The first harvest was on 15 August, when the color of the berries turned from purple to black. Berries were harvested on 6 different dates at 10–15 day intervals. The last harvest was on 27 October, when wrinkles appeared on the skin of the berries. On each harvest date, the weight of fruits collected from each plant was between 0.5–1.6 kg.

2.3. Analysis methods of physicochemical components

Pomological properties such as berry weight, firmness, soluble solid content (SSC), titratable acidity (TA), and pH were measured for fresh berries immediately after each harvest. For chemical analyses, berries were packed in polyethylene bags, frozen at –20 °C, and stored until the analyses. The weight of 100 berries is expressed in grams. Berry firmness was measured by penetrometer. For juice extraction, berries were homogenized with a blender and were then filtered to determine SSC, TA, and pH values. The rates of SSC were measured by handheld refractometer; TA was determined by titration with 0.1 N NaOH to an end point of pH 8.1, expressed in percentage of malic acid per 100 mL of juice; pH values were measured with a digital pH meter in 3 parallel ways for each replicate. The dry weight of fruit was determined with a gravimetric method (drying an aliquot of ~5 g fruit tissue at 105 °C to constant weight) according to the Turkish standard (TSE)-(TS 1129).

The anthocyanin content was measured by the pH differential method (Wada and Ou, 2002) and expressed as cyanidin-3-galactoside using the molar absorbance of e = 30,200 and molecular weight of 445.2. The content of total phenols was measured with Folin–Ciocalteu reagent (Thaipong et al., 2006). The data are expressed as mg of gallic acid equivalents (GAE) per 100 g of fresh weight. Antioxidant activity of aronia berry was determined using the stable 2,2- diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method (Thaipong et al., 2006). The standard curve was linear between 25 and 800 µM Trolox. Results are expressed in µM TE/g fresh weight. Total soluble tannins were determined by Folin–Denis assay (Lowry et al., 1951). The data are expressed as mg of tannic acid equivalents per 100 g and converted ppm. Condensed tannin content was measured by acid butanol assay (Bate-Smith, 1973), and expressed as cyanidin-3-galactoside using the molar absorbance of e = 30,200 and molecular weight of 445.2.

2.4. Statistical analysis

Four replicates of berry samples were analyzed for all traits for each harvest. The cultivars were analyzed separately. Statistical comparisons of the mean values were performed using one-way analysis of variance (ANOVA). LSMeans Student's t-test was used to find significant differences between harvest dates within the same cultivar ($P < 0.05$ confidence level), using JMP 14.1 trial version. Pairwise correlations were determined using the same JMP software, where $P < 0.05$ was considered significant.

3. Results and discussion

3.1. Changes in the physicochemical components of 'Nero' and 'Viking' aronia cultivars over the harvest period

The weight of 100 berries of 'Nero' was 96 g at date (dt) 1, and peaked 112 g at dt 3, and then decreased to 102 g at dt 6 (Table 1). That of 'Viking' was 93 g at dt 1, peaked at 103 g at dt 3, and then decreased to 101 g at dt 6 (Table 2). The loss of weight after dt 3 was observed in both cultivars, but at different rates, the lesser in 'Viking'. Jeppsson and Johansson (2000) reported that the weight of 100 berries of aronia increased significantly from 75 g to 99 g in 'Nero' and 'Viking' cultivars between 14–22 August, then fluctuated slightly until 8 September in Sweden. Ochmian et al. (2012) reported weight of 100 berries of 'Nero' as 91.7 g and that of 'Viking' as 99.5 g at harvest time. Our results are similar to previous findings.

Berry firmness of 'Nero' and 'Viking' decreased significantly over the harvest period, in total 40.2% and 43.5%, respectively (Tables 1 and 2). 'Nero' decreased from 433 $G.mm^{-1}$ at dt 1 to 259 $G.mm^{-1}$ at dt 6 (Table 1). 'Viking' decreased from 464 $G.mm^{-1}$ at dt 1 to 262 $G.mm^{-1}$ at dt 6 (Table 2). This study verifies previous findings, and its results are similar to the previous study conducted in Poland, where the firmness value recorded for 'Nero' was 338–586 $G.mm^{-1}$ and that of 'Viking' was 327–572 $G.mm^{-1}$ at harvest time (Ochmian et al., 2012). However, the firmness values after dt 3 were below the ones determined in Poland, which could be a result of the overripening of berries after dt 3.

pH value of 'Nero' was 3.62 at dt 1, peaked at 3.86 at dt 4, then decreased to 3.66 at dt 6 (Table 1). pH value of 'Viking' was 3.64 dt 1, peaked at 3.87 at dt 4, then decreased to 3.76 at dt 6 (Table 2). In fruits of *Rosaceae* family members and some berries, pH values increase with maturation (Karaçalı, 2004). In this study, however, pH values of aronia berries increased until 26 September, then decreased significantly on 12 and 27 October. The findings of this study are similar to the ones measured in Germany by Strigl et al. (1995), which were between 3.3 and 3.7. Similar pH values, which were between 3.3 and 3.9, were obtained in Japan by Tanaka and Tanaka (2001). On the other hand, our results differ from those measured by Bolling et al. (2015) in the USA, which were between 3.15 and 3.45, which may be due to ecological differences.

Titratable acidity of 'Nero' decreased 12.5% between dt 1 (0.610 g malic acid $100mL^{-1}$) and dt 4 (0.554 g $100mL^{-1}$), then increased 12.4% between dt 4 and dt 6 (Table 1). Similarly, that of 'Viking' decreased 14.3% between dt 1 (0.609 g malic acid $100mL^{-1}$) and dt 4 (0.522 g $100mL^{-1}$), then increased 11.9% between dt 4 and dt 6 (Table 2). Various researchers reported that the main acids identified in aronia berries were malic acid and citric acid (Kaack and Kühn, 1992; Strik et al., 2003; Snebergrova et al., 2014). Jeppsson and Johansson (2000) pointed out that malic acid (0.5 g $100mL^{-1}$) was the dominant organic acid in aronia berries. Ochmian et al. (2012) determined titratable acidity of 'Nero' to be 0.85 g $100mL^{-1}$ and that of 'Viking' to be 0.80 g $100mL^{-1}$ at harvest time. Likewise, Snebergrova et al. (2014) reported that acidity varied between 0.5 g $100mL^{-1}$ and 1.4 g $100mL^{-1}$ in aronia berries. The findings of this research are within the range found by previous researchers.

Soluble solids values of 'Viking' and 'Nero' berries did not change significantly over the harvest period (Table 1 and 2). The values ranged from 17.49% to 19.08% for 'Nero' and 17.33% to 19.42% for 'Viking'. Soluble solids in both cultivars reached their maximum on 26 September, and were then marked at the lowest level on 27 October.

Berry dry weight of 'Viking' was 21.69% at dt 1, peaked at 27.25% at dt 4, then decreased to 22.11% at dt 6 (Table 2), while that of 'Nero' did not change significantly (Table 1). According to Skupien and Oszmianski (2007) and Ochmian et al. (2012), dry matter content of berries ranges from 17% to 30%. Andrzejewska et al. (2015) reported that dry matter changed from 21% to 25.7% between 12 August and 27 October in Poland. The results of this study are within the range found in the abovementioned studies.

Anthocyanin value of 'Nero' peaked at 949.00 at dt 2, then decreased to 558.34 mg 100 g^{-1} at dt 6. As expected, anthocyanin content peaked earlier than total phenol content. However, that of 'Viking' was 674.49 mg 100 g^{-1} at dt 1, peaked at .26 mg 100 g^{-1} at dt 3, then decreased gradually until dt 5 (705.76 mg 100 g^{-1}) then sharply at dt 6 (413.94 mg 100 g^{-1}). According to a previous study by Ochmian et al. (2012), the chemical compositions of fruits of 'Nero' and 'Viking' are similar. However, we found that the anthocyanin content of 'Nero' is higher than that of 'Viking' in Turkey. Anthocyanin content of aronia berry reached its maximum on 8 September in Sweden. Interestingly, after that date, it showed only a small downward tendency at the end of September and remained steady in October (Jeppsson and Johansson, 2000). However, we observed a greater downward trend over September and a significant decrease in October. According to Zheng and Wang (2003) and Wu et al. (2004), anthocyanin content in aronia berry changed from 237 mg 100 g^{-1} to 990 mg 100 g^{-1}. The findings of this study are also within the range of results found in previous studies.

Total antioxidant activity of 'Nero' increased by 8.98% between dt 1 to dt 4, and then decreased gradually until dt 6. Similarly, that of 'Viking' increased by 13.9% from 802.71 μM TE 100 g FW^{-1} to 914.38 μM TE 100 g FW^{-1} between dt 1 and dt 4, and decreased by 1.98%

Table 1. Physiochemical components of 'Nero' aronia cultivar over the harvest period (mean ± SD).

Harvest time	Weight 100 berries (g)	Firmness ($G.mm^{-1}$)	Soluble solids (%)	Titratable acidity (g malic acid 100 mL^{-1})
1	96.00 ± 10.00 c	433.00 ± 52.00 a	18.04 ± 1.70	0.61 ± 0.06 a
2	104.00 ± 7.50 bc	345.00 ± 29.00 b	18.04 ± 1.74	0.58 ± 0.05 bc
3	112.00 ± 14.00 a	344.00 ± 43.00 b	18.37 ± 2.37	0.56 ± 0.03 cd
4	105.00 ± 11.00 b	325.00 ± 37.00 b	19.08 ± 2.20	0.55 ± 0.03 d
5	104.00 ± 15.00 bc	271.00 ± 35.00 c	17.55 ± 1.94	0.60 ± 0.00 ab
6	102.00 ± 13.00 bc	259.00 ± 47.00 c	17.49 ± 1.84	0.60 ± 0.05 ab
P value	0.0045	<0.0001	0.0983	<0.0001
Harvest time	pH	Dry weight (%)	Reducing sugar (%)	Total sugar (%)
1	3.62 ± 0.11 d	23.78 ± 1.23	18.40 ± 0.40 bc	18.96 ± 0.19 c
2	3.72 ± 0.14 bc	25.39 ± 1.75	20.66 ± 0.36 b	21.02 ± 0.31 b
3	3.79 ± 0.16 ab	27.96 ± 4.05	28.19 ± 4.83 a	28.88 ± 0.30 a
4	3.86 ± 0.14 a	26.34 ± 3.50	16.28 ± 1.10 cd	16.90 ± 0.85 d
5	3.67 ± 0.10 cd	26.12 ± 1.51	14.49 ± 0.31 de	15.04 ± 0.15 e
6	3.66 ± 0.05 cd	26.42 ± 1.44	13.04 ± 0.69 e	13.73 ± 0.49 f
P value	<0.0001	0.2761	<0.0001	<0.0001
Harvest time	Total anthocyanin (mg 100 g^{-1})	Total antioxidant (μM TE 100 g FW^{-1})	Total phenol (mg GA 100 g FW^{-1})	Total soluble tannin (ppm kg^{-1})
1	843.96 ± 10.67 b	837.71 ± 34.08 b	1899.70 ± 0.37	3.66 ± 0.59 bc
2	949.00 ± 36.79 a	903.75 ± 11.68 a	1927.00 ± 81.91	3.39 ± 0.39 c
3	932.41 ± 30.98 a	908.96 ± 7.68 a	1997.40 ± 38.81	3.19 ± 0.20 c
4	827.38 ± 26.77 b	912.92 ± 8.73 a	1922.20 ± 91.70	4.05 ± 0.23 ab
5	599.68 ± 66.17 c	903.75 ± 2.21 a	1916.30 ± 89.80	4.31 ± 0.16 a
6	558.34 ± 30.76 c	861.67 ± 33.37 b	1957.80 ± 46.33	3.33 ± 0.18 c
P value	0.0006	0.0003	0.5048	0.0026
Harvest time	Condensed tannin (mg 100 g^{-1})			
1	28.89 ± 1.28 ab			
2	23.66 ± 7.92 b			
3	23.22 ± 2.25 b			
4	27.05 ± 2.90 ab			
5	31.73 ± 1.91 a			
6	32.25 ± 2.27 a			
P value	0.014			

Different letters within the same column indicate significant differences ($P < 0.05$).

between dt 4 and dt 6. Aronia berries have very high antioxidative potential. A previous study by Andrzejewska et al. (2015) indicated that higher antioxidative properties of aronia berry derived from those harvested at the end of September in Poland. Likewise, in the USA, antioxidant activity of aronia berry decreased between 1–21 August, then increased until 12 September (Bolling et al., 2015). In our study, the upward trend continued until the end of September.

Changes in total phenols content of 'Nero' were not significant over the harvest period. However, that of 'Viking' increased from 1927.0 to 2016.4 mg GA 100 g FW^{-1} between dt 1 and dt 3, and decreased to 1942.9 mg GA 100 g FW^{-1} at dt 4, and then increased

Table 2. Physiochemical components of 'Viking' aronia cultivar over the harvest period (mean ± SD).

Harvest time	Weight 100 berries (g)	Firmness (G.mm⁻¹)	Soluble solids (%)	Titratable acidity (g malic acid 100 mL⁻¹)
1	93.00 ± 8.00 b	464.00 ± 38.00 a	18.10 ± 1.70	0.61 ± 0.11 a
2	102.00 ± 7.00 a	326.00 ± 45.00 b	18.15 ± 2.10	0.56 ± 0.03 bc
3	103.00 ± 15.00 a	321.00 ± 36.00 b	18.99 ± 2.78	0.54 ± 0.03 cd
4	102.00 ± 9.80 a	310.00 ± 46.00 bc	19.42 ± 2.48	0.52 ± 0.05 d
5	100.00 ± 11.00 a	288.00 ± 24.00 cd	17.94 ± 2.2	0.58 ± 0.02 ab
6	101.00 ± 8.70 a	262.00 ± 39.00 d	17.33 ± 1.01	0.58 ± 0.04 ab
P value	0.0313	<0.0001	0.0732	<0.0001
Harvest time	pH	Dry weight (%)	Reducing sugar (%)	Total sugar (%)
1	3.64 ± 0.18 d	21.69 ± 1.39b	20.28 ± 0.43 c	20.35 ± 0.47 c
2	3.67 ± 0.10 cd	21.41 ± 3.07b	20.74 ± 0.69 c	20.92 ± 0.65 c
3	3.79 ± 0.14 ab	27.07 ± 4.34a	22.24 ± 0.37 b	22.67 ± 0.32 b
4	3.87 ± 0.11 a	27.25 ± 3.51a	23.09 ± 0.53 ab	23.72 ± 0.36 ab
5	3.82 ± 0.25 ab	22.90 ± 3.87ab	23.88 ± 1.09 a	24.34 ± 1.15 a
6	3.76 ± 0.11 bc	22.11 ± 2.86b	18.61 ± 0.78 d	19.25 ± 0.82 d
P value	<0.0001	0.0463	<0.0001	<0.0001
Harvest time	Total anthocyanin (mg 100 g⁻¹)	Total antioxidant (μM TE 100 g FW⁻¹)	Total phenol (mg GA 100 g FW⁻¹)	Total soluble tannin (ppm kg⁻¹)
1	674.49 ± 17.84 c	802.71 ± 54.93 b	1927.00 ± 49.0b	3.13 ± 0.12
2	735.24 ± 31.08 ab	886.25 ± 5.87 a	1950.10 ± 48.4b	2.90 ± 0.21
3	770.26 ± 59.36 a	911.25 ± 3.63 a	2016.40 ± 35.1b	2.88 ± 0.32
4	762.88 ± 41.04 a	914.38 ± 8.32 a	1942.90 ± 61.1b	3.22 ± 0.21
5	705.76 ± 37.90 bc	910.21 ± 5.20 a	1966.60 ± 42.2b	3.06 ± 0.09
6	413.94 ± 34.17 d	896.25 ± 9.34 a	2120.70 ± 94.9a	2.73 ± 0.23
P value	0.0005	<0.0001	0.0103	0.0645
Harvest time	Condensed tannin (mg 100 g⁻¹)			
1	28.86 ± 1.09			
2	23.55 ± 5.25			
3	24.84 ± 3.93			
4	27.42 ± 3.36			
5	31.18 ± 4.72			
6	32.73 ± 4.47			
P value	0.0577			

Different letters within the same column indicate significant differences ($P < 0.05$).

again until dt 6. Jakobek et al. (2007) reported total phenolic contents of aronia berry as 7194 mg kg^{-1}. Other studies determined phenolic contents in 'Nero' to be 860–940 mg 100 g FW^{-1} (Hudec et al., 2006), and in 'Viking' to be 1052 mg 100 g FW^{-1} (Kahkönen et al., 2001). Another study reported that total phenolic contents increased by 24% over the 7 weeks between 1 August and 12 September in the USA (Bolling et al., 2015). In our study, it increased until 12 September, and then decreased. This could be related to ecological differences and overripening of berries after dt 3.

Condensed tannins of 'Nero' decreased from 28.89 to 23.22 mg cyanidine 3 galactoside (C3G) 100 g^{-1} between dt 1 and dt 3, and then increased 38.9% between dt 3 and dt 6. Similarly, total soluble tannins of 'Nero' decreased from 3.66 to 3.19 ppm until dt 3, and peaked 4.31 ppm at dt 5, but decreased to 3.33 ppm at dt 6. On the other hand, those of 'Viking' did not change significantly over the harvest period. Various studies showed that aronia berry has larger amounts of tannin than most fruits. Tannin content of aronia berry was determined to be 1.16% and that of its juice to be 0.85% in Poland (Pogorzelski et al., 2006), while that of its dry fruit was 2% (Atanassova and Bagdassarian, 2009). Proanthocyanidines constitute most of the condensed tannins. According to Bolling et al. (2015), aronia seed, pulp, and skin contain proanthocyanidines, but their distribution has yet to be determined. They reported that proanthocyanidine content of aronia juice increased 24% between 1 August and 12 September. In our study, we observed a similar upward trend in condensed tannin content of aronia berry.

We observed slight increases in total phenol and condensed tannin values of both cultivars at dt 5 and dt 6 (Figure 1). On the other hand, significant decreases were detected in antioxidant activity and anthocyanin content of 'Nero' after dt 3 and in those of 'Viking' after dt 4. Due to overripening of berries, an increase in ethylene levels may have caused a negative interaction with anthocyanin. In line with this, anthocyanin content of 'Nero' peaked 2 weeks earlier than that of 'Viking'. This can be considered a reason for 'Nero' reaching harvest ripening 2 weeks earlier than 'Viking'. A slight decrease observed in antioxidant activity can be considered a result of the decrease in anthocyanin content. Over the harvest period, anthocyanin content fluctuated (Figure 1). These fluctuations may be related to fruit maturation levels.

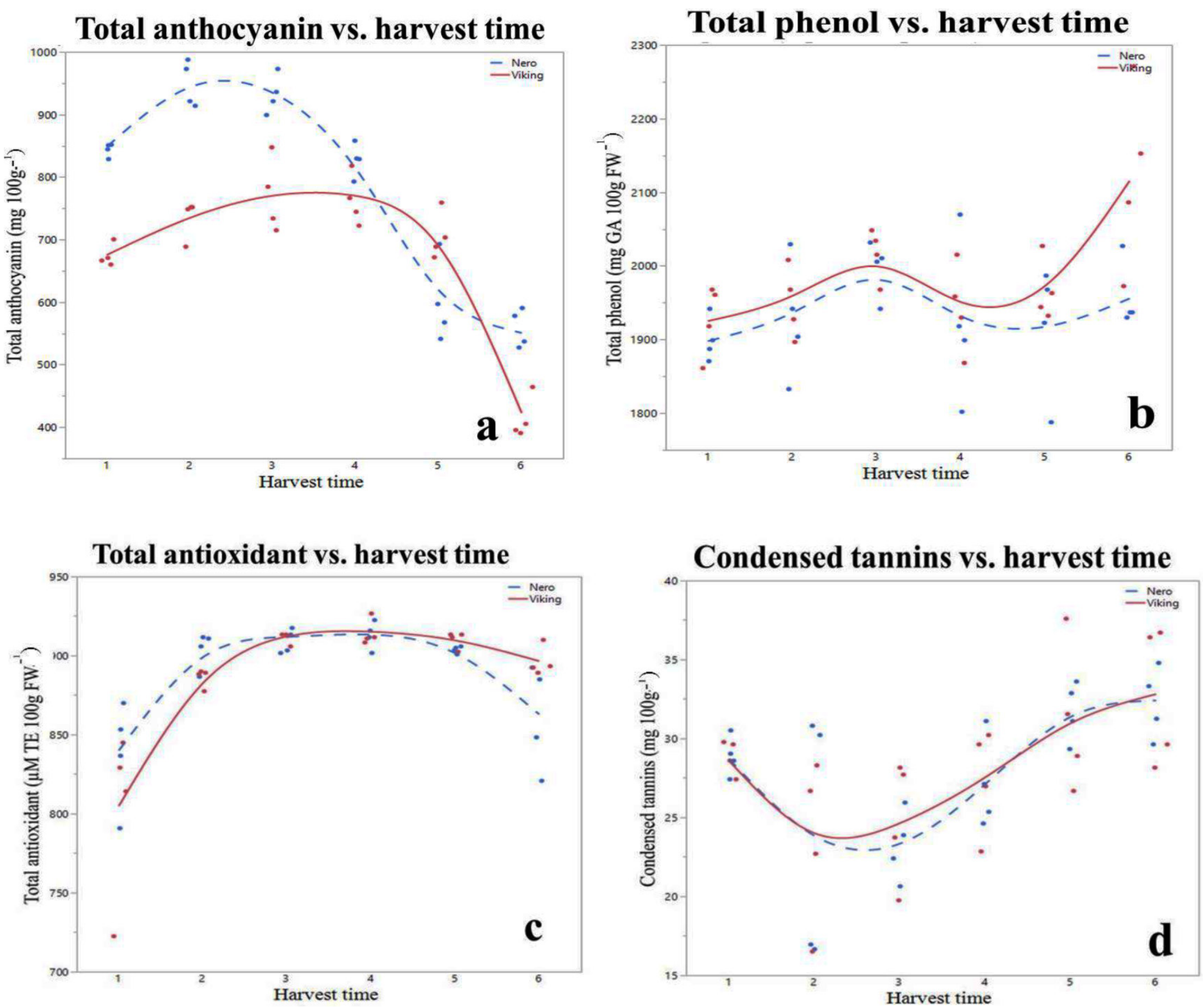

Figure 1. (a) Changes in anthocyanin contents, (b) total phenol content, (c) total antioxidant capacity, (d) condensed tannins of 'Nero' and 'Viking' aronia cultivars at harvest time. Data from 15 August to 27 October are included.

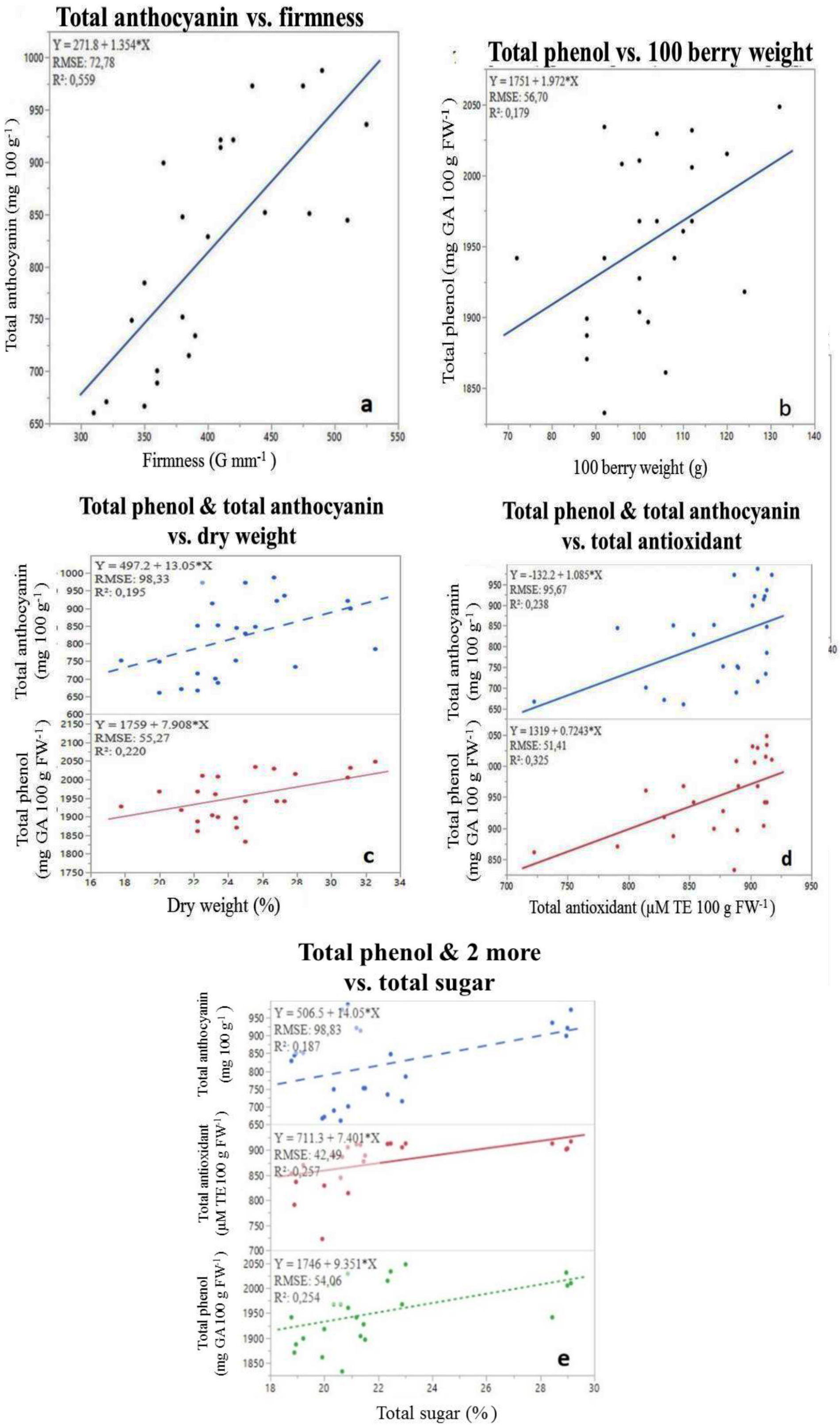

Figure 2. (a) Correlations between total anthocyanin content and firmness; (b) total phenol and 100 berry weight; (c) total phenol, total anthocyanin, and dry weight; (d) total phenol, total anthocyanin, and total antioxidant; (e) total antioxidant, total phenol, total anthocyanin, and total sugar for aronia berry cultivars 'Nero' and 'Viking'. Data from 15 August to 11 September are included.

When fruits ripened, anthocyanin content increased. However, when fruits overripened, anthocyanin content decreased, which is in line with a previous study in which it was reported that when blueberries lost fruit quality and firmness, anthocyanin content decreased (Krupa and Tomala, 2007; Retamales and Hancock, 2018).

Reducing sugar content of 'Nero' was 18.40 at dt 1, and peaked at 28.19 at dt 3, and then decreased to 13.04 at dt 6 (Table 1). Similarly, total sugar content increased by 34.3% between dt 1 and dt 3, then decreased to 13.73 at dt 6. As expected, reducing sugar value of 'Viking' showed a similar trend with dry matter over the harvest period (Table 2). Its value increased by 17.8% from dt 1 to dt 5, and then decreased 22.06% at dt 6. Similarly, total sugar content increased by 19.6% from 20.35% to 24.34% between dt 1 and dt 5, and then decreased by 20.9% at dt 6. A previous study reported that reducing sugar value of aronia berry changed between 13.0% and 16.0% in maturation (Kulling and Rawell, 2008). Another study showed that it changed from 6.8 to 8.8 mg.100 g^{-1} between 12 August and 22 October in Poland (Andrzejewska et al., 2015). Ochmian et al. (2012) reported that reducing sugar was 9.88 g 100 g^{-1} in 'Nero' and 8.83 g 100 g^{-1} in 'Viking', while total sugar was 10.25 g 100 g^{-1} in 'Nero' and 9.16 g 100 g^{-1} in 'Viking' at harvest time in Poland. However, this study found the highest reducing sugar value of 'Nero' to be 28.19%, and that of 'Viking' to be 23.88%, both of which are higher than the results of previous studies. This may also be related to ecological differences.

3.2. Correlations among physicochemical components

The highest correlation ($r = 0.75$, $P < 0.01$) was found between anthocyanin and firmness, which is in agreement with findings of a study by Retamales and Hancock (2018). In that study, the authors reported that the highest correlation ($r > 0.90$) was found between anthocyanin content and firmness of the 'Brigitta' blueberry cultivar.

Significant fluctuations were observed among physicochemical components between 11 September (dt 3) and 26 September (dt 4). After 26 September (dt 4), there were significant changes in all parameters. For this reason, data obtained over the first 3 harvest dates during which the fruit parameters peaked were used in correlations.

Previous studies showed that primary metabolites and secondary metabolites correlated with each other in fruits. Similarly, correlations between physicochemical properties and biochemical contents of aronia berry are shown in Figure 2.

Antioxidant activity was slightly correlated with total phenol content and total anthocyanin ($r = 0.57$, $P < 0.01$ and $r = 0.49$, $P < 0.05$) which is in line with a study by Fredes et al. (2014), which indicated that total antioxidant was slightly correlated with total phenol in raspberry, and another study by Kalt et al. (2000), which reported that total antioxidant was significantly correlated with total phenol and total anthocyanin in blueberry.

Total phenol content was slightly correlated with 100 berry weight ($r = 0.42$, $P < 0.05$), which is in line with the results of a previous study by Connor et al. (2002) who reported that total phenolic content was moderately correlated with 100 berry weight ($r = 0.44$, $P < 0.01$) in blueberry in Oregon. On the other hand, antioxidant activity and anthocyanin content showed no correlation with weight of 100 berries.

Total phenol, total antioxidant, and total anthocyanin were slightly correlated with sugars ($r = 0.50$, $P < 0.05$; $r = 0.51$, $P < 0.05$; $r = 0.43$, $P < 0.05$, respectively), while a previous study on grape berry in Australia by Pirie and Mullins (1977) reported a significant correlation of total phenolic content and anthocyanin with sugars ($r = 0.96$, $r = 0.95$), and showed the role of sugars in the regulation of phenolic biosynthesis in ripening grape berry.

4. Conclusion

The results confirmed aronia berry produced in Turkey to be a source of phenolic compounds with high antioxidant activity. Aronia can be consumed both fresh and after processing in various ways. For this reason, we harvested aronia berries at different dates over a long period to optimum harvest dates for either cultivar for various uses. As 100 berry weight is an important parameter for yield, the optimum harvest time for both cultivars was found to be the second week of September in terms of yield. Taking also into account anthocyanin content, antioxidant capacity, and total phenols, the health impacts of which are widely known, the optimum harvest time was determined to be the second and third weeks of September. The optimum harvest time for dry consumption was found to be in the first and second weeks of October when juice content decreased slightly, tannins increased, and anthocyanin content did not decrease significantly. No improvement in selection between the aronia berry cultivars 'Nero' and 'Viking' can be achieved, since both of them produced very similar results except for anthocyanin content, an increase of which in 'Nero' was observed 15 days earlier than that in 'Viking'. Overall, the results of this study showed the great potential of aronia berry for the development of foods rich in compounds with antioxidant properties.

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